



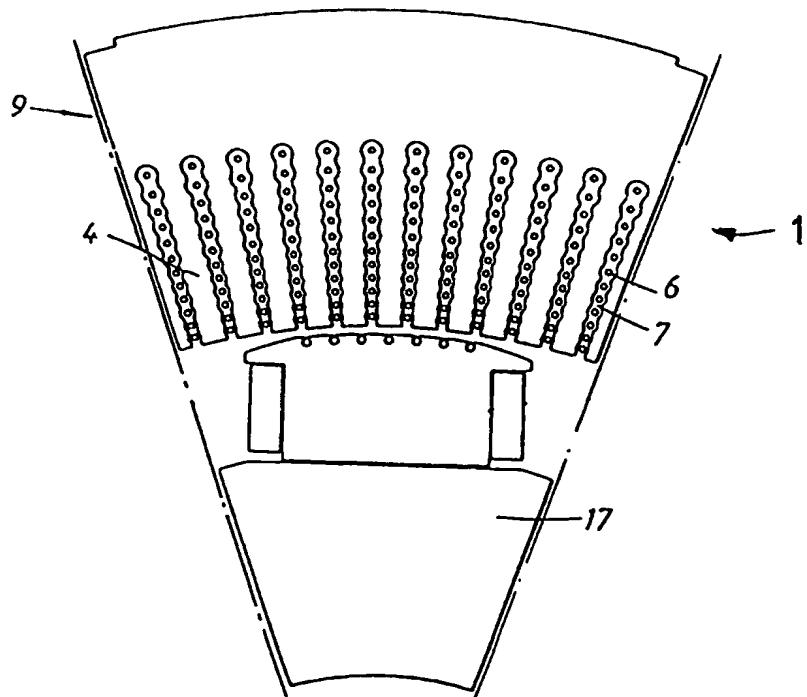
## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 :  H02K 3/40		A1	(11) International Publication Number: <b>WO 99/17427</b>  (43) International Publication Date: 8 April 1999 (08.04.99)
(21) International Application Number: PCT/SE98/01736 (22) International Filing Date: 29 September 1998 (29.09.98)  (30) Priority Data: 9703550-5 30 September 1997 (30.09.97) SE		(81) Designated States: AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, CZ (Utility model), DE, DE (Utility model), DK, DK (Utility model), EE, ES, FI, FI (Utility model), GB, GE, GH, GM, HR, HU, ID, IL, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SK (Utility model), SL, TJ, TM, TR, TT, UA, UG, US, UZ, VN, YU, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).	
(71) Applicant (for all designated States except US): ASEA BROWN BOVERI AB [SE/SE]; S-721 83 Västerås (SE). (72) Inventors; and (75) Inventors/Applicants (for US only): LEIJON, Mats [SE/SE]; Hyvlargatan 5, S-723 35 Västerås (SE). BERGGREN, Bertil [SE/SE]; Rönnbergagatan 2 B, S-723 46 Västerås (SE). (74) Agent: KARLSSON, Leif; L.A. Groth & Co. KB, P.O. Box 6107, S-102 32 Stockholm (SE).		Published <i>With international search report.</i>	

(54) Title: SYNCHRONOUS COMPENSATOR PLANT

## (57) Abstract

The magnetic circuit of a synchronous compensator plant is included in an electric machine which is directly connected to a high supply voltage of 20 – 800 kV, preferably higher than 36 kV. The electric machine is provided with solid insulation and its winding(s) is/are built up of a cable (6) intended for high voltage comprising one or more current-carrying conductors (31) with a number of strands (36) surrounded by at least one outer and one inner semiconducting layer (34, 32) and intermediate insulating layers (33). The plant is made as a mobile unit.



**FOR THE PURPOSES OF INFORMATION ONLY**

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AL	Albania	ES	Spain	LS	Lesotho	SI	Slovenia
AM	Armenia	FI	Finland	LT	Lithuania	SK	Slovakia
AT	Austria	FR	France	LU	Luxembourg	SN	Senegal
AU	Australia	GA	Gabon	LV	Latvia	SZ	Swaziland
AZ	Azerbaijan	GB	United Kingdom	MC	Monaco	TD	Chad
BA	Bosnia and Herzegovina	GE	Georgia	MD	Republic of Moldova	TG	Togo
BB	Barbados	GH	Ghana	MG	Madagascar	TJ	Tajikistan
BE	Belgium	GN	Guinea	MK	The former Yugoslav	TM	Turkmenistan
BF	Burkina Faso	GR	Greece		Republic of Macedonia	TR	Turkey
BG	Bulgaria	HU	Hungary	ML	Mali	TT	Trinidad and Tobago
BJ	Benin	IE	Ireland	MN	Mongolia	UA	Ukraine
BR	Brazil	IL	Israel	MR	Mauritania	UG	Uganda
BY	Belarus	IS	Iceland	MW	Malawi	US	United States of America
CA	Canada	IT	Italy	MX	Mexico	UZ	Uzbekistan
CF	Central African Republic	JP	Japan	NE	Niger	VN	Viet Nam
CG	Congo	KE	Kenya	NL	Netherlands	YU	Yugoslavia
CH	Switzerland	KG	Kyrgyzstan	NO	Norway	ZW	Zimbabwe
CI	Côte d'Ivoire	KP	Democratic People's	NZ	New Zealand		
CM	Cameroon		Republic of Korea	PL	Poland		
CN	China	KR	Republic of Korea	PT	Portugal		
CU	Cuba	KZ	Kazakhstan	RO	Romania		
CZ	Czech Republic	LC	Saint Lucia	RU	Russian Federation		
DE	Germany	LI	Liechtenstein	SD	Sudan		
DK	Denmark	LK	Sri Lanka	SE	Sweden		
EE	Estonia	LR	Liberia	SG	Singapore		

## SYNCHRONOUS COMPENSATOR PLANT

### Technical field:

The present invention relates to electric machines intended for connection 5 to distribution or transmission networks, hereinafter termed power networks. More specifically the invention relates to synchronous compensator plants for the above purpose, to the use of such a plant and to a method for phase compensation.

### Background art:

10 Reactive power is present in all electric power systems that transfer alternating current. Many loads consume not only active power but also reactive power. Transmission and distribution of electric power per se entails reactive losses as a result of series inductances in transformers, overhead lines and cables. Overhead lines and cables also produce reactive power as a result of capacitive connections 15 between phases and between phases and earth potential.

At stationary operation of an alternating current system, active power production and consumption must be in agreement in order to obtain nominal frequency. An equally strong coupling exists between reactive power balance and voltages in the electric power network. If reactive power consumption and production are not 20 balanced in a suitable manner, the consequence may be unacceptable voltage levels in parts of the electric power network. An excess of reactive power in one area leads to high voltages, whereas a deficiency leads to low voltages.

Contrary to active power balance at a nominal frequency, which is controlled solely with the aid of the active power control of the generator, a suitable 25 active power balance is obtained with the aid of both controllable excitation of synchronous generators and of other components spread out in the system. Examples of such (phase compensation) components are shunt reactors, shunt capacitors, synchronous compensators and SVCs (Static Var. Compensators).

The location of these phase compensation components in the electric 30 power network affects not only the voltage in various parts of the electric power network, but also the losses in the electric power network since the transfer of reactive power, like the transfer of active power, gives rise to losses and thus heating. It is consequently desirable to place phase compensation components so that losses

are minimized and the voltage in all parts of the electric power network is acceptable.

The shunt reactor and shunt capacitor are usually permanently connected or connected via a mechanical breaker mechanism to the electric power network.

5 In other words, the reactive power consumed/produced by these components is not continuously controllable. The reactive power produced/consumed by the synchronous compensator and the SVC, on the other hand, is continuously controllable. These two components are consequently used if there is a demand for high-performance voltage control.

10 The following is a brief description of the technology for phase compensation with the aid of synchronous compensator and SVC.

A synchronous compensator is in principle a synchronous motor running at no load, i.e. it takes active power from the electric power network equivalent to the machine losses.

15 The rotor shaft of a synchronous compensator is usually horizontal and the rotor generally has six or eight salient poles. The rotor is usually dimensioned thermally so that the synchronous compensator, in over-excited state, can produce approximately 100 % of the apparent power the stator is thermally dimensioned for (rated output) in the form of reactive power. In under-excited state, when the synchronous compensator consumes reactive power, it consumes approximately 60 % of the rated output (standard value, depending on how the machine is dimensioned). This gives a control area of approximately 160 % of rated output over which the reactive power consumption/production can be continuously controlled. If the machine has salient poles with relatively little reactance in transverse direction, and 20 is provided with excitation equipment enabling both positive and negative excitation, more reactive power can be consumed than the 60 % of rated output stated above, without the machine exceeding the stability limit. Modern synchronous compensators are normally equipped with fast excitation systems, preferably a thyristor-controlled static exciter where the direct current is supplied to the rotor via slip rings.

25 30 This solution enables both positive and negative supply as above.

The magnetic circuits in a synchronous compensator usually comprise a laminated core, e.g. of sheet steel with a welded construction. To provide ventilation and cooling the core is often divided into stacks with radial and/or axial ventilation

tion ducts. For larger machines the laminations are punched out in segments which are attached to the frame of the machine, the laminated core being held together by pressure fingers and pressure rings. The winding of the magnetic circuit is disposed in slots in the core, the slots generally having a cross section in the shape of a 5 rectangle or trapezium.

In multi-phase electric machines the windings are made as either single or double layer windings. With single layer windings there is only one coil side per slot, whereas with double layer windings there are two coil sides per slot. By coil side is meant one or more conductors combined vertically or horizontally and provided with a common coil insulation, i.e. an insulation designed to withstand the 10 rated voltage of the machine to earth.

Double-layer windings are generally made as diamond windings whereas single layer windings in the present context can be made as diamond or flat windings. Only one (possibly two) coil width exists in diamond windings whereas flat 15 windings are made as concentric windings, i.e. with widely varying coil width. By coil width is meant the distance in arc dimension between two coil sides pertaining to the same coil.

Normally all large machines are made with double-layer winding and coils of the same size. Each coil is placed with one side in one layer and the other side in 20 the other layer. This means that all coils cross each other in the coil end. If there are more than two layers these crossings complicate the winding work and the coil end is less satisfactory.

It is considered that coils for rotating machines can be manufactured with good results up to a voltage range of 10 - 20 kV.

25 A synchronous compensator has considerable short-duration overload capacity. In situations when electro-mechanical oscillations occur in the power system the synchronous compensator can briefly supply reactive power up to twice the rated output. The synchronous compensator also has a more long-lasting overload capacity and is often able to supply 10 to 20 % more than rated output for up to 30 30 minutes.

Synchronous compensators exist in sizes from a few MVA to hundreds of MVA. The losses for a synchronous compensator cooled by hydrogen gas amount

to approximately 10 W/kvar, whereas the corresponding figure for air-cooled synchronous compensators is approximately 20 W/kvar.

Synchronous compensators were preferably installed in the receiving end of long radial transmission lines and in important nodes in masked electric power net-  
5 works with long transmission lines, particularly in areas with little local generation. The synchronous compensator is also used to increase the short-circuit power in the vicinity of HVDC inverter stations.

The synchronous compensator is most often connected to points in the electric power network where the voltage is substantially higher than the synchro-  
10 nous compensator is designed for. This means that, besides the synchronous compensator, the synchronous compensator plant generally includes a step-up transformer, a busbar system between synchronous compensator and transformer, a generator breaker between synchronous compensator and transformer, and a line breaker between transformer and electric power network.

15 In recent years SVCs have to a great extent replaced synchronous compensators in new installations because of their advantages particularly with regard to cost, but also in certain applications because of technical advantages.

The SVC concept (Static Var. Compensator) is today the leading concept for reactive power compensation and, as well as in many cases replacing the syn-  
20 chronous compensator in the transmission network, it also has industrial applica-  
tions in connection with electric arc furnaces. SVCs are static in the sense that, contrary to synchronous compensators, they have no movable or rotating main components.

SVC technology is based on rapid breakers built up of semi-conductors,  
25 thyristors. A thyristor can switch from nonconductor to conductor in a few millionths of a second. Capacitors and reactors can be connected or disconnected with negligible delay with the aid of thyristor bridges. By combining these two components reactive power can be steplessly either supplied or extracted.

A SVC plant typically consists of both capacitor banks and reactors and  
30 since the thyristors generate harmonics, the plant also includes harmonic filters. Besides control equipment, a transformer is also required between the compensation equipment and the network in order to obtain optimal compensation from the

size and cost point of view. SVC plant is available in size from a few MVA up to 650 MVA, with nominal voltages up to 765 kV.

Various SVC plant types exist, named after how the capacitors and reactors are combined. Two usual elements that may be included are TSC or TCR. TSC is 5 a thyristor-switched reactive power-producing capacitor and TCR is a thyristor-switched reactive power-consuming reactor. A usual type is a combination of these elements, TSC/TCR.

The magnitude of the losses depends much on which type of plant the SVC belongs to, e.g. a FC/TCR type (FC means that the capacitor is fixed) has considerably greater losses than a TSC/TCR. The losses for the latter type are approximately comparable with the losses for a synchronous compensator. 10

It should be evident from the above summary of the phase compensation technology that this can be divided into two principal concepts, namely synchronous compensation and SVC.

15 These concepts have different strengths and weaknesses. Compared with the synchronous compensator, the SVC has the main advantage of being cheaper. However, it also permits somewhat faster control which may be an advantage in certain applications.

The drawbacks of the SVC as compared with the synchronous compensa- 20 tor include:

- it has no overload capacity. In operation at its capacitive limit the SVC becomes in principle a capacitor, i.e. if the voltage drops then the reactive power production drops with the square of the voltage. If the purpose of the phase compensation is to enable transfer of power over long distances the lack of overload capacity means that, in order to avoid stability problems, a higher rated output must be chosen if SVC plant is selected than if synchronous compensator plant is selected.
- it requires filters if it includes a TCR.
- it does not have a rotating mass with internal voltage source. This is an advantage with the synchronous compensator, particularly in the vicinity of HVDC

30 transmission.

In order to achieve a more competitive electricity market many countries have deregulated, or are in the process of deregulating, the electricity market. This usually involves a separation of power production and transmission services into

separate entities. When these two parts of the system are in different hands, the previously existing link between the planning of generation plants and transmission lines is broken. A generation plant owner may announce the closing of a generation plant at timescales which are, for hardware investments, very short, presenting the 5 operators and planners of transmission services with major changes in both load flow patterns and the location of controllable reactive production/consumption resources at short notice. Consequently, there is a strategic need for a phase compensation unit that can be relocated, within short lead time, to an arbitrary node in the transmission system.

10        In countries where the electricity market has not been deregulated there may also exist a need to have relocatable phase compensation components. For instance, countries with a large share of nuclear power production may encounter situations similar to that described above. Normally, nuclear power plants are closed down once a year, during a low load season, for inspections and reparations. 15        However, occasionally these plants may have to stay closed for longer periods of time due to major reparations. Although this situation is easier to handle in a country which has not deregulated the electricity market, the size of a typical nuclear plant may imply that the changes in load flow patterns and the absence of controllable reactive production/consumption resources puts the operators of the 20 transmission system in situations which are difficult to handle while maintaining prescribed security standards. There exists a need for a relocatable phase compensation unit also in these situations.

      There exist today a small number of relocatable SVC plants, see e.g. the article "Relocatable static var compensators help control unbundled power flows" in 25 the Magazine "Modern Power Systems", December 1996, pages 49-54. In addition to the differences between a static and a synchronous compensator described above, the relocatable static compensator involves a number of containers, which requires a fairly large area at the site and which needs to be electrically interconnected at the site. But most importantly the relocatable static compensator can only 30 be connected to nodes in the transmission system where a step-down transformer already is available, providing a fairly low voltage. In other words, the relocatable static compensator cannot be directly connected to the transmission system voltage (typically 130 kV and up).

Due to the number of components required in a synchronous compensator plant and in particular the up to now necessary presence of a transformer, synchronous compensator plants for high-voltage networks up to now have been realized solely as stationary plants. In case of change in an existing power network regarding the need for phase compensation the plant might be superfluous at its location or might be required to be designed and dimensioned different, or a plant might be required somewhere else in the network. This of course is a serious drawback with such a stationary plant.

10 Description of the invention:

The object of the present invention is to attain a synchronous compensator plant avoiding this drawback.

According to the invention this object has been achieved in that a synchronous compensator plant of the kind specified in the preamble of claim 1 includes 15 the specific features specified in the characterizing portion of the claim.

Thanks to the fact that the winding(s) in the rotating electric machine in the synchronous compensator plant is/are manufactured with a special solid insulation, a voltage level can be achieved for the machine which is far above the limits a conventional synchronous compensator can be practically or financially constructed for.

20 The voltage level may reach any level applicable in power networks for distribution and transmission. The advantage is thus achieved that the synchronous compensator can be connected directly to such networks without intermediate connection of a step-up transformer.

25 Elimination of the transformer per se entails great savings in cost, weight and space, but also has other decisive advantages over a conventional synchronous compensator plant.

The efficiency of the plant is increased. Moreover, reactive losses incurred by the transformer's consumption of reactive power are avoided and so is the resultant shift in phase angle. This has a positive effect as regards the static and dynamic 30 stability margins of the system. Furthermore, a conventional transformer contains oil, which entails a fire risk. This is eliminated in a plant according to the invention, and the requirement for various types of fire-precautions is reduced. Many

other electrical coupling components and protective equipment are also reduced. This gives reduced plant costs and less need for service and maintenance.

These and other advantages result in a synchronous compensator plant being considerably smaller and less expensive than a conventional plant, and that 5 the operating economy is radically improved thanks to less maintenance and smaller losses.

Thanks to these advantages a synchronous compensator plant according to the invention will contribute to this concept being financially competitive with the SVC concept (see above) and even offering cost benefits in comparison with this.

10 The fact that the invention makes the synchronous compensator concept competitive in comparison with the SVC concept therefore enables a return to the use of synchronous compensator plants. The drawbacks associated with SVC compensation are thus no longer relevant. The complicated, bulky banks of capacitors and reactors in a SVC plant are one such drawback. Another big drawback 15 with SVC technology is its static compensation which does not give the same stability as that obtained by the inertia obtained in a rotating electric machine with its rotating e.m.f. as regards both voltage and phase angle. A synchronous compensator is therefore better able to adjust to temporary disturbances in the network and to fluctuations in the phase angle. The thyristors that control a SVC plant are also 20 sensitive to displacement of the phase angle. A plant according to the invention also enables the problem of harmonics to be solved.

The synchronous compensator plant according to the invention thus enables the advantages of synchronous compensator technology over SVC technology to be exploited so that a more efficient and stable compensation is obtained at 25 a cost superior to this from the point of view of both plant investment and operation.

The plant according to the invention is small, inexpensive, efficient and reliable, both in comparison with a conventional synchronous compensator and a SVC.

The reduction of the amount of required components in the plant and in particular the elimination of the transformers in the plant makes the design of the 30 plant as a mobile unit possible, which thus is included as an essential feature of claim 1. By making the plant as a mobile unit that can be transported by a lorry, a railway truck, a helicopter or the like, the plant can be moved from one location of a

power network to another, should the need for phase compensation in the network change.

With a synchronous compensator plant having components with windings of the specific construction as claimed in claim 1 and making use of the possibility 5 to design the plant as a mobile unit the drawbacks related to stationary synchronous compensator plants thus are overcome. This is primarily of relevance for high-voltage networks, in particular in the range of 36 kV and above.

Another object of the invention is to satisfy the need for fast, continuously controllable reactive power which is directly connected to sub-transmission or 10 transmission level in order to manage the system stability and/or dependence on rotating mass and the electro-motive force in the vicinity of HVDC transmission. The plants shall be able to supply anything from a few MVA up to several hundreds of MVA.

The advantage gained by satisfying said objects is the avoidance of the intermediate transformer, the reactance of which otherwise consumes reactive 15 power. This also enables the avoidance of traditional so-called generator breakers. Advantages are also obtained as regards network quality since there is rotating compensation. With a plant according to the invention the overload capacity is also increased, which with the invention may be +100 %. The synchronous compensator 20 according to the invention may be given higher overload capacity in over-excited operation than conventional synchronous compensators, both as regards short-duration and long-duration overload capacity. This is primarily because the time constants for heating the stator are large with electric insulation of the stator winding according to the invention. However, the thermal dimensioning of the rotor must 25 be such that it does not limit the possibilities of exploiting this overload capacity.

To accomplish this the magnetic circuit in the electric machine included in the synchronous compensator plant is formed with threaded permanent insulating cable with included earth. The invention also relates to a procedure for manufacturing such a magnetic circuit.

30 The major and essential difference between known technology and the embodiment according to the invention is thus that this is achieved with an electric machine provided with solid insulation, the magnetic circuit(s) of the winding(s) being arranged to be directly connected via breakers and disconnectors to a high supply

voltage of between 20 and 800 kV, preferably higher than 36 kV. The magnetic circuit thus comprises a laminated core having a winding consisting of a threaded cable with one or more permanently insulated conductors having a semiconducting layer both at the conductor and outside the insulation, the outer semiconducting 5 layer being connected to earth potential.

To solve the problems arising with direct connection of electric machines to all types of high-voltage power networks, a machine in the plant according to the invention has a number of features as mentioned above, which differ distinctly from known technology. Additional features and further embodiments are defined in the 10 dependent claims and are discussed in the following.

Such features mentioned above and other essential characteristics of the synchronous compensator plant and the electric machine according to the invention included therein, include the following:

- The winding of the magnetic circuit is produced from a cable having one or 15 more permanently insulated conductors with a semiconducting layer at both conductor and sheath. Some typical conductors of this type are XLPE cable or a cable with EP rubber insulation which, however, for the present purpose are further developed both as regards the strands in the conductor and the nature of the outer sheath.  
XLPE = crosslinked polyethylene. EP = ethylene propylene.
- 20 • Cables with circular cross section are preferred, but cables with some other cross section may be used in order to obtain better packing density, for instance.
  - Such a cable allows the laminated core to be designed according to the invention in a new and optimal way as regards slots and teeth.
- 25 • The winding is preferably manufactured with insulation in steps for best utilization of the laminated core.
  - The winding is preferably manufactured as a multi-layered, concentric cable winding, thus enabling the number of coil-end intersections to be reduced.
  - 30 • The slot design is suited to the cross section of the winding cable so that the slots are in the form of a number of cylindrical openings running axially and/or radially outside each other and having an open waist running between the layers of the stator winding.

• The design of the slots is adjusted to the relevant cable cross section and to the stepped insulation of the winding. The stepped insulation allows the magnetic core to have substantially constant tooth width, irrespective of the radial extension.

5 • The above-mentioned further development as regards the strands entails the winding conductors consisting of a number of impacted strata/layers, i.e. insulated strands that from the point of view of an electric machine, are not necessarily correctly transposed, uninsulated and/or insulated from each other.

10 • The above-mentioned further development as regards the outer sheath entails that at suitable points along the length of the conductor, the outer sheath is cut off, each cut partial length being connected directly to earth potential.

15 The use of a cable of the type described above allows the entire length of the outer sheath of the winding, as well as other parts of the plant, to be kept at earth potential. An important advantage is that the electric field is close to zero within the coil-end region outside the outer semiconducting layer. With earth potential on the outer sheath the electric field need not be controlled. This means that no field concentrations will occur either in the core, in the coil-end regions or in the transition between them.

20 The mixture of insulated and/or uninsulated impacted strands, or transposed strands, results in low stray losses.

25 The cable for high voltage used in the magnetic circuit winding is constructed of an inner core/conductor with a plurality of strands, at least two semiconducting layers, the innermost being surrounded by an insulating layer, which is in turn surrounded by an outer semiconducting layer having an outer diameter in the order of 20-250 mm and a conductor area in the order of 30-3000 mm<sup>2</sup>.

The insulated conductor or cable used in the present invention is flexible and of a kind which is described in more detail in WO 97/45919 and WO 97/45847. Additional descriptions of the insulated conductor or cable concerned can be found in WO 97/45918, WO 97/45930 and WO 97/45931.

30 Accordingly, the windings, in the arrangement according to the invention, are preferably of a type corresponding to cables having solid, extruded insulation, of a type now used for power distribution, such as XLPE-cables or cables with EPR-insulation. Such a cable comprises an inner conductor composed of one or more

strand parts, an inner semiconducting layer surrounding the conductor, a solid insulating layer surrounding this and an outer semiconducting layer surrounding the insulating layer. Such cables are flexible, which is an important property in this context since the technology for the arrangement according to the invention is based 5 primarily on winding systems in which the winding is formed from cable which is bent during assembly. The flexibility of an XLPE-cable normally corresponds to a radius of curvature of approximately 20 cm for a cable with a diameter of 30 mm, and a radius of curvature of approximately 65 cm for a cable with a diameter of 80 mm. In the present application the term "flexible" is used to indicate that the winding 10 is flexible down to a radius of curvature in the order of four times the cable diameter, preferably eight to twelve times the cable diameter.

The winding should be constructed to retain its properties even when it is bent and when it is subjected to thermal or mechanical stress during operation. It is vital that the layers retain their adhesion to each other in this context. The material 15 properties of the layers are decisive here, particularly their elasticity and relative coefficients of thermal expansion. In an XLPE-cable, for instance, the insulating layer consists of cross-linked, low-density polyethylene, and the semiconducting layers consist of polyethylene with soot and metal particles mixed in. Changes in volume as a result of temperature fluctuations are completely absorbed as changes 20 in radius in the cable and, thanks to the comparatively slight difference between the coefficients of thermal expansion in the layers in relation to the elasticity of these materials, the radial expansion can take place without the adhesion between the layers being lost.

The material combinations stated above should be considered only as examples. Other combinations fulfilling the conditions specified and also the condition 25 of being semiconducting, i.e. having resistivity within the range of  $10^{-1}$ - $10^6$  ohm-cm, e.g. 1-500 ohm-cm, or 10-200 ohm-cm, naturally also fall within the scope of the invention.

The insulating layer may consist, for example, of a solid thermoplastic material 30 such as low-density polyethylene (LDPE), high-density polyethylene (HDPE), polypropylene (PP), polybutylene (PB), polymethyl pentene ("TPX"), cross-linked materials such as cross-linked polyethylene (XLPE), or rubber such as ethylene propylene rubber (EPR) or silicon rubber.

The inner and outer semiconducting layers may be of the same basic material but with particles of conducting material such as soot or metal powder mixed in.

The mechanical properties of these materials, particularly their coefficients of thermal expansion, are affected relatively little by whether soot or metal powder is mixed in or not - at least in the proportions required to achieve the conductivity necessary according to the invention. The insulating layer and the semiconducting layers thus have substantially the same coefficients of thermal expansion.

Ethylene-vinyl-acetate copolymers/nitrile rubber (EVA/NBR), butyl graft polyethylene, ethylene-butyl-acrylate copolymers (EBA) and ethylene-ethyl-acrylate copolymers (EEA) may also constitute suitable polymers for the semiconducting layers.

Even when different types of material are used as base in the various layers, it is desirable for their coefficients of thermal expansion to be substantially the same. This is the case with the combination of the materials listed above.

The materials listed above have relatively good elasticity, with an E-modulus of  $E < 500$  MPa, preferably  $< 200$  MPa. The elasticity is sufficient for any minor differences between the coefficients of thermal expansion for the materials in the layers to be absorbed in the radial direction of the elasticity so that no cracks appear, or any other damage, and so that the layers are not released from each other. The material in the layers is elastic, and the adhesion between the layers is at least of the same magnitude as in the weakest of the materials.

The conductivity of the two semiconducting layers is sufficient to substantially equalize the potential along each layer. The conductivity of the outer semiconducting layer is sufficiently high to enclose the electrical field within the cable, but sufficiently low not to give rise to significant losses due to currents induced in the longitudinal direction of the layer.

Thus, each of the two semiconducting layers essentially constitutes one equipotential surface, and these layers will substantially enclose the electrical field between them.

There is, of course, nothing to prevent one or more additional semiconducting layers being arranged in the insulating layer.

According to a particularly preferred embodiment of the invention, at least two of these layers, preferably all three, have the same coefficient of thermal expansion. The decisive benefit is thus achieved that defects, cracks or the like are avoided at thermal movement in the winding.

5 The invention also relates to a procedure for manufacturing the magnetic circuit for the electric machine included in the synchronous compensator plant. The procedure entails the winding being placed in the slots by threading the cable through the cylindrical openings in the slots.

From another aspect of the invention, the object has been achieved in that  
10 a plant of the type described in the preamble to claim 35 is given the special features defined in the characterizing part of this claim.

Since the insulation system, suitably permanent, is designed so that from the thermal and electrical point of view it is dimensioned for over 36 kV, the plant  
15 can be connected to high-voltage power networks without any intermediate step-up transformer, thereby achieving the advantages referred to above. Such a plant is  
preferably, but not necessarily, constructed to include the features defined for the  
plant as claimed in any of claims 1-34.

The above-mentioned and other advantageous embodiments of the invention are defined in the dependent claims.

20

Brief description of the drawings:

The invention will be described in more detail in the following detailed description of a preferred embodiment of the construction of the magnetic circuit of the electrical machine in the synchronous compensator plant, with reference to the accompanying drawings in which  
25

Figure 1 shows a single line diagram of the invented synchronous compensator plant.

Figure 2 shows a schematic axial end view of a sector of the stator in an electric machine in the synchronous compensator plant according to the invention, and  
30

Figure 3 shows an end view, step-stripped, of a cable used in the winding of the stator according to Figure 2

Figure 4 schematically shows the invented plant transported on a lorry.

Description of a preferred embodiment:

Figure 1 shows a single line diagram of the synchronous compensator plant according to a preferred embodiment of the invention, where the machine is arranged for direct connection to the power network, without any step-up transformer, at two different voltage levels.

In the schematic axial view through a sector of the stator 1 according to Figure 2, pertaining to the electric machine included in the synchronous compensator plant, the rotor 17 of the machine is also indicated. The stator 1 is composed in 10 conventional manner of a laminated core. Figure 2 shows a sector of the machine corresponding to one pole pitch. From a yoke part 9 of the core situated radially outermost, a number of teeth 4 extend radially in towards the rotor 17 and are separated by slots 7 in which the stator winding is arranged. Cables 6 forming this stator winding, are high-voltage cables which may be of substantially the same type as 15 those used for power distribution, i.e. XLPE cables, but without any outer, mechanically-protective sheath. Thus, the semiconducting layer which is sensitive to mechanical damage lies naked on the surface of the cable.

The cables 6 are illustrated schematically in Figure 2, only the conducting central part of each cable part or coil side being drawn in. As can be seen, each 20 slot 7 has varying cross section with alternating wide parts and narrow parts. The wide parts are substantially circular and surround the cabling, the waist parts between these forming narrow parts. The waist parts serve to radially fix the position of each cable. The cross section of the slot 7 also narrows radially inwards. This is 25 because the voltage on the cable parts is lower the closer to the radially inner part of the stator 1 they are situated. Slimmer cabling can therefore be used there, whereas coarser cabling is necessary further out. In the example illustrated, cables of three different dimensions are used, arranged in three correspondingly dimensioned sections of slots 7.

Figure 3 is showing a cross section through a high voltage winding 6 used 30 in the present invention. The high voltage winding 6 comprises a current-carrying conductor in the form of a number of strands 12 with circular cross sections which strands 12 are arranged in the middle of the high voltage winding 6. Around the strands 12 there is a first layer 13 with semiconducting properties. Around the first semiconducting layer 13 is arranged a layer of solid insulation 14 for example

XLPE-insulation. Around the insulation layer 14 there is a second layer 15 with semiconducting properties. The diameter of the high voltage winding is 20 - 250 mm and the conducting area lies in the interval of 80 - 3000 mm<sup>2</sup>.

5 The three layers are arranged to adhere to each other even when the cable is bent. The cable shown is flexible, and this property is maintained during the entire life of the cable.

In figure 4 it is schematically illustrated how the complete plant constitutes a mobile unit 21 that can be transported on a lorry.

---

CLAIMS

1. A synchronous compensator plant comprising at least one rotating electric machine having at least one winding, **characterized** in that the winding in at least 5 one of the electric machines comprises an insulation system including at least two semiconducting layers, each layer constituting essentially an equipotential surface and also including solid insulation disposed therebetween, and in that the plant is a mobile unit in the sense that with regard to size and weight and number of components substantially the complete unit (21) is transportable by a lorry, a railway truck, 10 or a helicopter.
2. A plant as claimed in claim 1, **characterized** in that at least one of the layers has substantially the same coefficient of thermal expansion as the solid insulation.
3. A plant as claimed in either of claims 1 or 2, **characterized** in that the insulation is built up of a cable (6) intended for high voltage and comprising one or more current-carrying conductors (12) surrounded by at least one semiconducting layer (13, 15) with intermediate insulating layer (14) of solid insulation.
4. A plant as claimed in claim 3, **characterized** in that the innermost semiconducting layer (13) is at substantially the same potential as the conductor(s) (12).
5. A plant as claimed in either of claims 3 or 4, **characterized** in that the one 25 of the outer semiconducting layers (15) is arranged to form essentially an equipotential surface surrounding the conductor(s) (12).
6. A plant as claimed in claim 5, **characterized** in that said outer semiconducting layer (15) is connected to a selected potential.
7. A plant as claimed in claim 6 **characterized** in that the selected potential is 30 earth potential.

8. A plant as claimed in any of claims 3-7 **characterized** in that at least two of said layers have substantially the same coefficient of thermal expansion.

9. A plant as claimed in any of claims 3-5, **characterized** in that the current carrying conductor comprises a plurality of strands, only a few of the strands being uninsulated from each other.

10. A plant as claimed in any of claims 1-9, **characterized** in that the winding consists of a cable comprising one or more current-carrying conductors (12), each conductor consisting of a number of strands, an inner semiconducting layer (13) being arranged around each conductor, an insulating layer (14) of solid insulation being arranged around each inner semiconducting layer (13) and an outer semiconducting layer (5) being arranged around each insulating layer (14).

15 11. An arrangement according to any of claims 1-10, **characterized** in that said layers (13, 14, 15) are arranged to adhere to one another even when the insulated conductor or cable is bent.

20 12. A plant as claimed in claim 10, **characterized** in that the cable also comprises a metal screen and a sheath.

13. A plant as claimed in any of the preceding claims, **characterized** in that the magnetic circuit is arranged in a rotating electric machine, the stator (3) of which is cooled at earth potential.

25 14. A plant as claimed in any of the preceding claims, **characterized** in that the magnetic circuit of the electric machine comprises a stator winding placed in a slot (5), said slot (5) being designed as a number of cylindrical openings (7) running axially and radially outside each other, having substantially circular cross section and separated by narrow waist parts (8) between the cylindrical openings.

30 15. A plant as claimed in claim 14, **characterized** in that the phases of the stator winding are Y-connected.

16. A plant as claimed in claim 15 **characterized** in that the Y-point of the stator winding is insulated from earth potential or connected to earth potential via a high-ohmic impedance and protected from over-voltages by means of surge arresters.

5

17. A plant as claimed in claim 15, **characterized** in that the Y-point of the stator winding is earthed via a suppression filter of third harmonic type, which suppression filter is designed to greatly reduce or eliminate third harmonic currents in the electric machine at the same time as being dimensioned to limit voltages and 10 currents in the event of faults in the plant.

18. A plant as claimed in claim 17, **characterized** in that the suppression filter is protected from over-voltages by means of surge arresters, the latter being connected in parallel with the suppression filter.

15

19. A plant as claimed in claims 3 and 15, **characterized** in that the cable (6) constituting the stator winding has a gradually decreasing insulation seen from the high-voltage side towards the Y-point.

20 20. A plant as claimed in claim 19, **characterized** in that the gradual decrease in the insulation thickness is step-wise or continuous.

21. A plant as claimed in claims 14 and 19, **characterized** in that the circular cross section (7) of the substantially cylindrical slots (5) for the stator winding has 25 decreasing radius seen from the yoke portion towards the rotor.

22. A plant as claimed in any of claims 13-21, **characterized** in that the rotating part has an inertia and electromotive force.

30 23. A plant as claimed in claim 22, **characterized** in that the machine can be started from a local power supply.

24. A plant as claimed in claim 23, **characterized** in that the machine has two or more poles.

25. A plant as claimed in claim 24, **characterized** in that the rotor (2) and the 5 stator (3) are so dimensioned that at nominal voltage, nominal power factor and over-excited operation, the thermally based current limits of stator and rotor are exceeded approximately simultaneously.

26. A plant as claimed in claim 24, **characterized** in that the rotor (2) and the 10 stator (3) are so dimensioned that at nominal voltage, nominal power factor and over-excited operation, the thermally based stator current limit is exceeded before the thermally based rotor current limit has been exceeded.

27. A plant as claimed in either of claims 25 or 26, **characterized** in that it has 15 100% overload capacity at nominal voltage, nominal power factor and at over-excited operation.

28. A plant as claimed in claim 25 or claim 26, **characterized** in that the rotor poles are pronounced.

20

29. A plant as claimed claim 29, **characterized** in that the quadrature-axis synchronous reactance is considerably less than the direct-axis synchronous reactance.

25 30. A plant as claimed claim 29, **characterized** in that the machine is equipped with excitation systems enabling both positive and negative excitation.

31. A plant as claimed in any of claims 3-30 **characterized** in that the cables (6) with solid insulation intended for high voltage have a conductor area between 30 30 and 3000 mm<sup>2</sup> and have an outer cable diameter of between 20 and 250 mm.

32. A plant as claimed in any of the preceding claims, **characterized** in that the stator and rotor circuits (3, 2) are provided with cooling means in which the coolant is in liquid and/or gaseous form.

5 33. A plant as claimed in any of the preceding claims, **characterized** in that the machine is arranged for connection to several different voltage levels.

34. A plant as claimed in any of claims 1-33, **characterized** in that the machine is connected to the power network without any step-up transformer.

10 35. A plant as claimed in any of the preceding claims, **characterized** in that the winding of the machine is arranged for self-regulating field control and lacks auxiliary means for control of the field.

15 36. A plant as claimed in any of the preceding claims, **characterized** in that the winding has an insulation system which, as regards its thermal and electrical properties, permits a voltage level in the machine exceeding 36 kV.

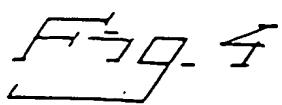
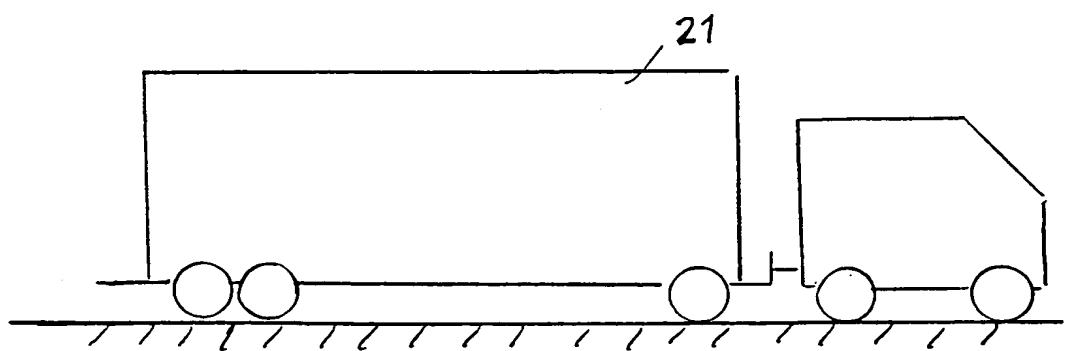
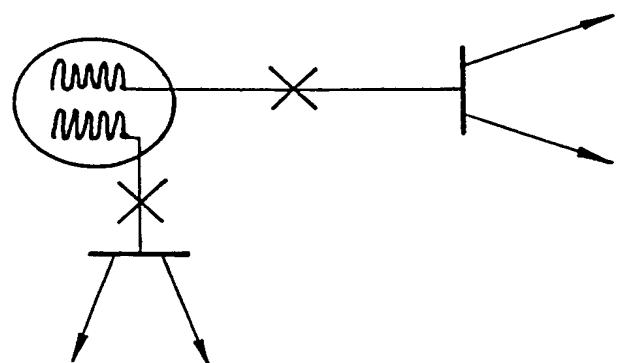
37. A plant as claimed in any of the preceding claims, **characterized** in that the  
20 plant is mounted on wheels.

38. The use of a plant according to any of claims 1-37 for phase compensation at different localities of a high voltage power network.

25 39. A method for phase compensation in a high voltage power network **characterized** in that a plant according to any of claims 1-36 is transported between different localities in the network for phase compensation at these different localities.

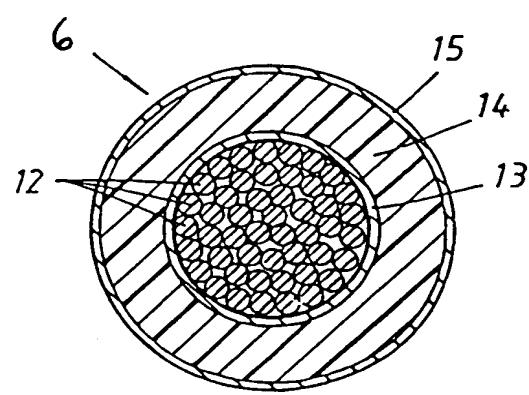
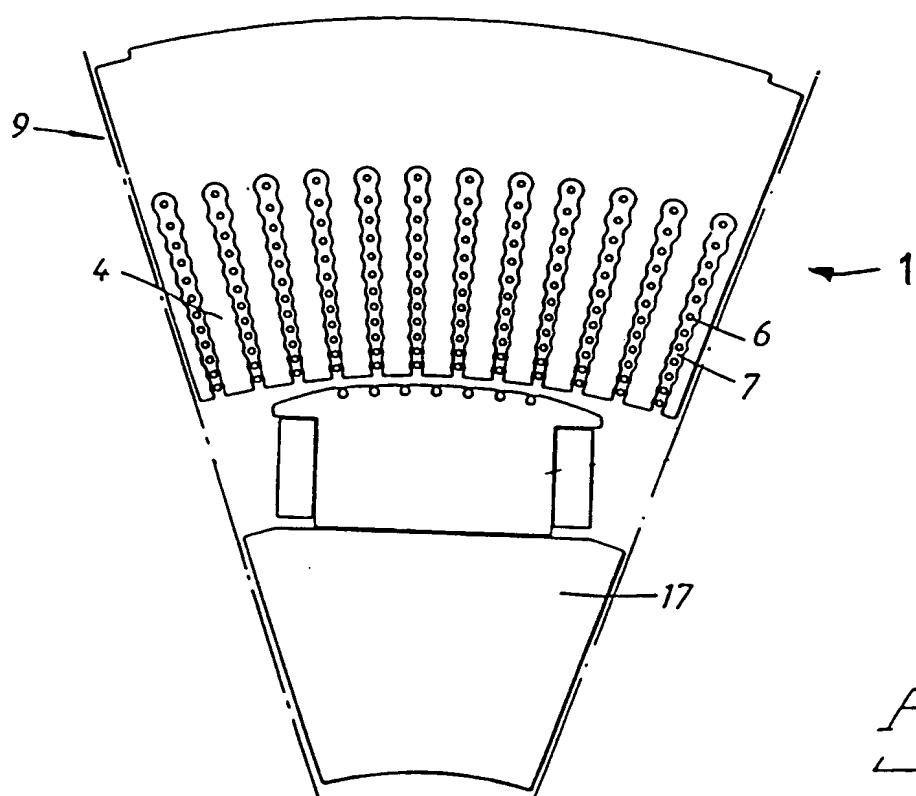
---

1/2



SUBSTITUTE SHEET (RULE 26)

2/2



## INTERNATIONAL SEARCH REPORT

International application No.  
PCT/SE 98/01736

## A. CLASSIFICATION OF SUBJECT MATTER

IPC6: H02K 3/40

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC6: H02K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

WPI

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 4785138 A (O. BREITENBACH ET AL.), 15 November 1988 (15.11.88), see the whole document  --	1-16,19-22, 24,28,30-32, 35,37-39
Y	US 4368418 A (F.P. DEMELLO ET AL.), 11 January 1983 (11.01.83), abstract  --	1-16,19-22, 24,28,30-32, 35,37-39
Y	SU 955369 A (BEZCHASTNO G.A. ET AL.), 30 August 1982*(30.08.82), figure 1, abstract  --	14

Further documents are listed in the continuation of Box C.

See patent family annex.

- \* Special categories of cited documents:
- "A" document defining the general state of the art which is not considered to be of particular relevance
- "E" earlier document but published on or after the international filing date
- "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- "O" document referring to an oral disclosure, use, exhibition or other means
- "P" document published prior to the international filing date but later than the priority date claimed

- "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
- "X" document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
- "Y" document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
- "&" document member of the same patent family

Date of the actual completion of the international search

8 December 1998

Date of mailing of the international search report

11-12-1998

Name and mailing address of the ISA/  
Swedish Patent Office  
Box 5055, S-102 42 STOCKHOLM  
Facsimile No. + 46 8 666 02 86

Authorized officer

Karin Säfsten  
Telephone No. + 46 8 782 25 00

## INTERNATIONAL SEARCH REPORT

International application No.  
PCT/SE 98/01736

## C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 4429244 A (P.Z. NIKITIN ET AL.), 31 January 1984 (31.01.84), figure IV, abstract --	19-21
A	US 4091139 A (J.F. QUIRK), 23 May 1978 (23.05.78), abstract --	1-16, 19-22, 24, 28, 30-32, 35, 37-39
A	US 4551780 A (M. CANAY), 5 November 1985 (05.11.85), abstract --	17, 18
A	US 5036165 A (R.K. ELTON ET AL.), 30 July 1991 (30.07.91), abstract -- -----	1-16, 19-22, 24, 27, 30-32, 35, 37-39

**INTERNATIONAL SEARCH REPORT**

Information on patent family members

03/11/98

International application No.

PCT/SE 98/01736

Patent document cited in search report	Publication date	Patent family member(s)		Publication date
US 4785138 A	15/11/88	DE	3543106 A,C	11/06/87
US 4368418 A	11/01/83	CA	1169125 A	12/06/84
		EP	0076848 A	20/04/83
		WO	8203734 A	28/10/82
SU 955369 A	30/08/82	NONE		
US 4429244 A	31/01/84	CA	1167898 A	22/05/84
		CH	663120 A,B	13/11/87
		DE	3050139 T	25/03/82
		FR	2473804 A,B	17/07/81
		GB	2081523 A,B	17/02/82
		JP	56501707 T	19/11/81
		SU	961048 A	23/09/82
		WO	8101775 A	25/06/81
US 4091139 A	23/05/78	BE	846361 A	17/03/77
		CA	1071480 A	12/02/80
		CH	607251 A	30/11/78
		DE	2641406 A	31/03/77
		GB	1565696 A	23/04/80
		JP	1047401 C	28/05/81
		JP	52036783 A	22/03/77
		JP	55041483 B	24/10/80
US 4551780 A	05/11/85	AU	533597 B	01/12/83
		AU	5094879 A	17/07/80
		CA	1134901 A	02/11/82
		CH	651975 A,B	15/10/85
		DE	2903790 A	24/07/80
		FR	2446553 A,B	08/08/80
		SE	446289 B,C	25/08/86
		SE	8000104 A	11/07/80
US 5036165 A	30/07/91	US	5066881 A	19/11/91
		US	5067046 A	19/11/91
		CA	1245270 A	22/11/88
		US	4853565 A	01/08/89

PCT

WORLD INTELLECTUAL PROPERTY ORGANIZATION  
International Bureau



INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : H02K 3/40		A1	(11) International Publication Number: <b>WO 99/17427</b> (43) International Publication Date: 8 April 1999 (08.04.99)
(21) International Application Number: PCT/SE98/01736 (22) International Filing Date: 29 September 1998 (29.09.98)		(81) Designated States: AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, CZ (Utility model), DE, DE (Utility model), DK, DK (Utility model), EE, ES, FI, FI (Utility model), GB, GE, GH, GM, HR, HU, ID, IL, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SK (Utility model), SL, TJ, TM, TR, TT, UA, UG, US, UZ, VN, YU, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).	
(30) Priority Data: 9703550-5 30 September 1997 (30.09.97) SE		Published <i>With international search report.</i>	
(71) Applicant (for all designated States except US): ASEA BROWN BOVERI AB [SE/SE]; S-721 83 Västerås (SE).			
(72) Inventors; and			
(73) Inventors/Applicants (for US only): LEIJON, Mats [SE/SE]; Hyvlargatan 5, S-723 35 Västerås (SE). BERGGREN, Bertil [SE/SE]; Rönnbergsgatan 2 B, S-723 46 Västerås (SE).			
(74) Agent: KARLSSON, Leif, L.A. Groth & Co. KB, P.O. Box 6107, S-102 32 Stockholm (SE).			
(54) Title: SYNCHRONOUS COMPENSATOR PLANT			
(57) Abstract			
<p>The magnetic circuit of a synchronous compensator plant is included in an electric machine which is directly connected to a high supply voltage of 20 – 800 kV, preferably higher than 36 kV. The electric machine is provided with solid insulation and its winding(s) is/are built up of a cable (6) intended for high voltage comprising one or more current-carrying conductors (31) with a number of strands (36) surrounded by at least one outer and one inner semiconducting layer (34, 32) and intermediate insulating layers (33). The plant is made as a mobile unit.</p>			
